NOAA STRATEGIC AQUACULTURE SCIENCE PLAN – JUNE 2019

Comments and edits are recommended by the MAFAC Aquaculture Task Force for MAFAC consideration and approval on July 1, 2019 meeting.

Introduction and Overview

Strong science programs are a key to regulatory efficiency and industry development. NOAA's Science serves regulatory processes by developing tools for informed and objective decision making at multiple levels of government. NOAA's Science serves ~~industry~~ aquaculture producers~~development~~ by focusing on technology to improve farm and industry level economic performance while easing environmental and social costs of production, addressing resource scarcity and insuring food security, and providing a platform for sustainable innovation.[1] Science provides the foundation for marine resource management and~~,~~ seafood production through aquaculture~~, and innovation~~. The Department of Commerce Strategic Plan 2018-2022 (Table 1) highlights this support for science, research, and knowledge advancement in aquaculture. The Strategic Plan contains two objectives for aquaculture. Paraphrased to articulate science's role in achieving them, these objectives are:

1. Develop intelligent regulatory and ~~industry~~ aquaculture farm management decision-making tools, and
2. Support research and development to address key production challenges to support increased sustainable production.

These two objectives align with how NOAA has approached fisheries research historically: science for sustainable natural resource management and science to innovate past farming ~~industry~~ bottlenecks and reduce negative impacts. These two themes address questions of environmental interactions, production efficiency, and risk mitigation among many others. In addressing these objectives, researchers always need to consider the social, economic and environmental aspects of the innovations they are championing.

A third type of NOAA science relates to the day to day needs for science to inform commerce and the public. This includes annual statistics on seafood production, food safety certifications needed for sale of aquaculture products across political boundaries and proactively communicating scientific findings that solve or mitigate natural resource management, environmental interactions, production efficiencies, risk mitigation to the general public but specifically to internal and external critics that are misinformed by unsustainable aquaculture practices in other countries and are not familiar with US farming practices, the assistance to US farmers rendered by a nationwide research and extension effort, and the state and federal

[1] Béné, C., M. Barange, R. Subasinghe, R. Pinstrup-Andersen, G. Merino, G. Hemre and M. Williams. 2015. Feeding 9 billion by 2050 – Putting fish back on the menu. Food Security 7(2): 261-274.
Asche, F. and M.D. Smith. 2018. Viewpoint: Induced innovation in fisheries and aquaculture. Food Policy. 76:1-7. https://doi.org/10.1016/j.foodpol.2018.02.002

complex regulatory environment. This sort of science is strongly rooted in specific applications and brings a different set of opportunities closely tied to the regulatory need they address.

Regulatory decision making demands objectivity, efficiency, and timeliness. These goals require managers to evaluate proposals and information in a timely manner, and base decisions on best available science[2]. The enabling technological support includes science-based tools to smartly site and manage farms including, minimizing negative impacts to protected species and habitats, evaluating risks associated with disease, and genetic risks of breeding between escaped farmed and wild populations, among others. Tools can be models, maps, guidelines, review documents, NEPA analyses, and a variety of other synthesis products. The goal is for regulatory decision-makers to have the confidence to approve or deny an application, or make other management decisions quickly, objectively, and consistently, assured that the best available science is already imbedded in the tool.

Industry production and competitiveness requires science and technology that will improve industry's economic, environmental and social performance. Science and technology products typically include: 1) physical items such as feed ingredients, prototypes of all kinds, improved genetic material; 2) methods to produce seed organisms, breeding, manage health, ensure product safety, design structures, analytical procedures; 3) understanding to use data on genomics, genetics, epidemiology, economics; and 4) reoccurring data products to aid in commerce or management over long time periods. The farther away from commercialization this type of research is, the less attractive it is for industry funding. Likewise, the smaller an industry is, the more important government sponsored pre-competitive research is. The US marine aquaculture industry is small and diverse, with high demands for all types of government funded research.

Section 1 of this plan outlines NOAA's scientific assets[3]that can be used to address the objectives discussed. Specific scientific disciplines, resources and topics needed to advance these objectives are further broken down by scientific area in Section 2. Each section starts with a vision statement meant to be aspirational and ends with a list of recommendations (not yet written). Recommendations are further addressed in the third section (not yet written) as they apply regionally and by marine aquaculture sector (fish, shellfish, seaweeds, type of culture, etc.) and by budget implications.

The process of creating new ideas often occurs when people with a diverse mix of basic and applied research[4] interests and end users interact, and key infrastructure is available to extend what is known to new areas or scales. Much has been written on the conditions needed for

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[2] https://www.st.nmfs.noaa.gov/science-quality-assurance/

[3] Scientific Assets as used in this document include all ways that NOAA spends money on scientific deliverables. This includes grant programs, NOAA laboratories, international agreements, contracts and internal staff work on programs such as statistics, and others.

[4] Stokes, Donald E. (1997). Pasteur's Quadrant – Basic Science and Technological Innovation. Brookings Institution Press. p. 196. ISBN 9780815781776.

innovation (Appendix 1-Draft). Key conditions that improve the chances for innovation include issues of connectivity, communication, size and diversity of effort (critical mass and the adjacent possible), infrastructure, flexibility and stability of resources within the research enterprise and other attributes.

Table 1 - Key Background Documents and Terms of Reference upon which this Plan was developed.

Plan Name and Link	Description quoted directly from plans
Federal Strategic Plan	This document is the strategic plan to guide Federal research in aquaculture. The plan describes ways that government can help advance and expand domestic interests in aquaculture, providing for greater economic and recreational opportunities in the United States. The plan identifies the current Federal resources in research and extension, the need for the best research to inform public policy and regulatory decisions, and the need for improved public understanding of aquaculture, its diversity, and potential benefits and risks.
Sea Grant Vision Document	The purpose of this 10-year vision is to (1) determine Sea Grant's most appropriate roles over the next 10 years, and (2) identify priority research and outreach strategies leading to sustainable economic development, environmental conservation and social well-being.
NOAA Aquaculture Plan	The Marine Aquaculture Strategic Plan is intended to guide efforts within NOAA Fisheries to support development of sustainable marine aquaculture from 2016 to 2020. The plan features four main goals: regulatory efficiency, science tools for sustainable management, technology development and transfer, and an informed public.
NOAA Science Center Review	This document is a summary of the formal peer review of the aquaculture science conducted at NOAA's Fisheries Science Centers during 2016 and 2017. It provides a brief overview of how the Aquaculture Science Program review was conducted, summarizes the key issues reviewers identified during the review, and presents individual Fisheries Science Center and a national-level response for those issues identified during the review.
NOAA Strategic Plan	The objectives identified in NOAA's Next-Generation Strategic Plan are the basis for NOAA's corporate planning, performance management, and stakeholder engagement over the next five years.
DOC Strategic Plan	The Department has one overarching goal: Helping the American Economy Grow. Each of the Department's five strategic goals advances the mission and supports this goal: Accelerate American leadership Enhance job creation Strengthen U.S. economic and national security Fulfill constitutional requirements and support economic activity Deliver customer-centric service excellence
Ocean Policy	This order maintains and enhances benefits to the Nation through improved public access to marine data and information, efficient

	interagency coordination on ocean-related matters, and engagement with marine industries, the science and technology community, and other ocean stakeholders
Terms of Reference for this document	Developed with input from the NMFS Science Board and others

Section 1. Creating an environment for innovation: using NOAA's Science Assets for Innovation

Vision: Align and manage NOAA's aquaculture science assets to optimize the creation and end-use of scientific information needed for sound management and development of a sustainable US marine aquaculture industry.

The expression "it takes a village" applies to innovation needed for developing a science-based aquaculture industry which simultaneously addresses social, economic and environmental goals. Questions are best addressed by coordinated governmental, industry, NGOs, and academic partners that is exemplified by the stakeholder advisory capacities utilized for laboratory, program and grant review. In addition, the Subcommittee on Aquaculture (SCA) is in place and serves as the Federal interagency coordinating group to increase the overall effectiveness and productivity of Federal aquaculture research, regulation, technology transfer, and assistance programs.

There are multiple structures and institutes that all play a role in creating, funding, directing, transferring and ultimately using science and technology for meaningful aquaculture development. Table 2 highlights the strengths of federal labs, external grant programs, extension and other specialized approaches. These include the use of Prizes (Open Innovation), and International Science Agreements, as well as, the collection of government statistics which all also have roles to play and bring unique strengths needed to meet NOAA's objectives. Table 3 highlights types and examples of key enabling infrastructure. These make up the portfolio of scientific assets that NOAA has to address the needs of its customers for science.

The Strengths of Federal Labs

Regulatory Streamlining

NOAA's federal labs play an especially important role in the final stages of developing tools for management due to the requirements of the Information Quality Act and because there is typically little commercial value in the majority of tools designed for government decision making. Also, some tools, notably those incorporating spatial analysis benefit from restricted datasets only available to federal employees with security clearances (e.g., DOD data), and require long term upkeep, improvement and delivery to be useful.

Science for Industry Innovation

Federal labs can be important to provide long-term stable focal points for industry research. Long-term stable funding of national labs allows them to develop key infrastructure such as hatcheries, feed mills, pilot scale grow-out facilities, genetics programs, and reference analytical labs (e.g., National Seafood Inspection Lab) that would be difficult to sustain without such long-term security. It should be noted that such key infrastructure also exists at universities and NGOs which enjoy long-term support from State, Federal and/or foundation resources[5]. These facilities often focus on local development, ongoing stock enhancement programs, or are shared with other agriculture or fisheries sectors. Invariably, key infrastructure when made available broadly to researchers is necessary, but not sufficient, for innovation (see feeds sidebar example).

In addition, federal labs work as conveners and coordinators of research that directly addresses federal goals, is regional or national in scope, and can be available in short timeframes needed by decision makers. Scientists at federal labs can quickly adjust to annual strategic plans and be responsive to the need for information to address unanticipated regulatory needs or to consult on emerging industry issues within their area of expertise.

Science to facilitate Commerce - Seafood Inspection
NOAA Fisheries works to ensure confidence in U.S. seafood by protecting and strengthening the seafood market through global trade, establishing partnerships with industry and consumer groups, providing seafood inspection services, and analyzing seafood safety risks. The National Seafood Inspection Laboratory (NSIL) provides analyses, data management, regulatory compliance risk analysis, and technology transfer expertise to meet seafood safety responsibilities. The lab shares seafood and aquatic animal health information and data with other federal and state agencies, academia, industry, media, and seafood consumers. This includes chemical, microbiological and species identification analysis needed for commerce and trade in seafood. NSIL also serves as a reference lab for the private laboratory sector.

Science to facilitate Commerce - Statistics
It is the responsibility of the federal government to collect national statistics on the aquaculture industry. It is important that NOAA's national marine aquaculture statistics are a trusted, consistent, accurate and timely source of data that most effectively informs science, regulatory and outreach efforts in support of a growing domestic marine aquaculture industry. Information on industry growth and performance needs to be communicated at different levels so that the importance of the industry is understood by a diverse range of stakeholder groups (i.e., the general public, farmers, agency administration, regulators, lawmakers, NGOs, scientists, media, etc.). Ultimately, the growth of the industry recorded from annual statistics is a measure of the effectiveness of NOAA's aquaculture program - including the science component of that program. This is useful for tracking and reporting progress and for planning, budgeting and allocation of funds. Finally, statistical data transcends international language barriers and portrays information that is common to and understood by all global participants.

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[5] However there have also been some painful and abrupt closures of such facilities which were not beneficial to NOAA's long-term aquaculture goals when funding was withdrawn by federal, state or foundation benefactors.

The Strengths of External Research

In the realm of federally funded external research, there are numerous models, but two most applicable for aquaculture research are; competitive individual grants and longer-term partnerships such as cooperative institutes. NOAA currently administers competitive grants programs for 1-3 year aquaculture projects and works with 33 universities that make up the National Sea Grant College Program on state level aquaculture research and extension. NOAA also funds aquaculture grants through the Saltonstall-Kennedy Grant Program, Small Business Innovative Research Grant Program and occasionally through other grant programs. NOAA does not yet have or use the consortium or cooperative institute approach focused on specific aquaculture needs that would benefit from a 5-10 year partnership effort.

The NOAA Sea Grant Aquaculture Vision Document[6] provides three conclusions that illustrates the strengths of competitive grants. These are:

- Invest in priorities that target critical issues and needs as identified by stakeholders throughout the coastal United States, but allow maximum flexibility to address regional, state and local issues and needs relevant to the aquaculture industry.
- Support projects and activities that are multidimensional in scope and focus, address issues and opportunities holistically, apply an integrated mix of research, education, extension and/or communications approaches, and when applicable, directly involve stakeholders and the industry.
- Invest in geographically and topically diverse integrated aquaculture research and outreach efforts.

Researchers supported by competitive grants are be best suited to addressing short term 1-4 year research projects, address emerging industry needs, and a much wider range of topics (diversity) compared to national labs. Competitive grants add diversity, bring in innovative ideas from outside the field, and can be the glue to connect industry, state, research institutions and extension programs. Grant programs can help maintain the connection between basic science and application. The competitive nature of grants keeps the quality of science at a high level. These shorter-term research efforts enhance, and are enhanced by, the scientific backbone created by longer term programs that support key infrastructure such as at federal or cooperative labs.

Regulatory Streamlining

Grants can be used to conduct background analysis of laws and policies and make recommendations to address or change them. Funds can also be used for law and policy workshops and to facilitate dialogue among permitting agencies and the regulated public[7]. A key resource in this area is the National Sea Grant Law Center. Law Center attorneys contribute to the field of ocean and coastal law and policy through the analysis of current issues and the

[6] From Sea Grant Association. 2016. NOAA Sea Grant 10-Year Aquaculture Vision. MASGP-16-015.

[7] From Sea Grant Association. 2016. NOAA Sea Grant 10-Year Aquaculture Vision. MASGP-16-015.

publication of their research results[8]. Grant funded researchers provide information that is independent of regulatory responsibilities, improving the diversity and quality of regulatory decision making.

Science for Industry Innovation

The majority of grants are provided for industry innovation. Sea Grant, for example, has key topic foci on developing species production technology from both the biological and engineering perspective, and in seafood safety and quality. This includes emphasis on hatchery and seed stock production technologies for current and emerging species and to develop new and enhance existing seafood safety tools and new products[9].

Science to facilitate Commerce

A priority of Sea Grant is to "Provide economic and marketing research and associated outreach programming to increase the profitability and environmental sustainability of aquaculture businesses[10]." The Saltonstall-Kennedy Grant Program funds projects that address the needs of fishing communities, optimize economic benefits, and increase other opportunities to keep working waterfronts viable[11]. Small Business Innovative Research Grants[12] fund businesses to explore ways to commercialize technologies and de-risk technological advancement. Clearly, grants to research institutes and industry can go a long way to pushing late stage research out the door and improving the economic performance of the aquaculture industry.

The Unique Role of Extension

The US is rare among nations in having active extension services focused on agriculture and aquaculture. The USDA National Institute for Food and Agriculture (NIFA) supports extension primarily in freshwater aquaculture, while NOAA Sea Grant supports extension primarily in marine aquaculture. Both agencies coordinate aquaculture extension at the national level through the National Aquaculture Extension Steering Committee (NAESC) which is run by leadership elected by, and from extension agents supported by NOAA Sea Grant and/or USDA/NIFA. The NAESC has ex-officio input from national offices of USDA NIFA and NOAA (Sea Grant and Office of Aquaculture). The importance of the extension service in facilitating the creation of useful science, and then transferring that science to the end user cannot be overstated. The extension service is a large part of why the US leads in science and technology generally, serving as a professional connection between research institutes and the users of scientific information[13].

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[8] http://nsglc.olemiss.edu

[9] From Sea Grant Association. 2016. NOAA Sea Grant 10-Year Aquaculture Vision. MASGP-16-015.

[10] From Sea Grant Association. 2016. NOAA Sea Grant 10-Year Aquaculture Vision. MASGP-16-015.

[11] https://www.fisheries.noaa.gov/grant/saltonstall-kennedy-grant-program

[12] https://www.fisheries.noaa.gov/grant/small-business-innovation-research-program

[13] Kumar, G., C. Engle and C. Tucker. 2018. Factors driving aquaculture technology adoption. Journal of the World Aquaculture Society. 49(3):447-476.

NOAA Fisheries also has a small number of Regional Aquaculture Coordinators. NOAA Fisheries Regional Coordinators in many ways function similarly to extension agents but focus on connecting regulatory personnel from numerous state and federal agencies (including NOAA) with science based regulatory tools, and helping industry navigate the regulatory process. Coordinators also work with agency and non-agency scientists to develop regulatory tools and advice.

Regulatory Streamlining

NOAA Fisheries Regional Coordinators in many ways function as ombudsmen connecting regulatory personnel from numerous state and federal agencies with the best available science and industry. Sea Grant Extension also works to get high-quality unbiased information to coastal managers, and sometimes tests the permitting process with grant supported applications. Both coordinators and extension agents work with industry to navigate the permitting process and facilitate workshops on numerous key issues leading to common understanding among industry, regulators and scientists.

Science for Industry Innovation

The Sea Grant extension network excels at delivering science to industry and communicating industry needs back to the research community.

Science to facilitate Commerce

Seafood inspectors provide companies with assurance that their products are fit for commerce.

Combined Models for Research and Extension

Combining different types of science assets may provide a way to produce synergy as the strengths of one type of asset can balance the weaknesses of other assets (see sidebar on Development of Alternative Feeds). This may come with an increased need for coordination, priority setting and administration. Consortia, cooperative institutes, Cooperative Research and Development Act agreements, and other partnerships of government agencies with universities, private companies, NGOs and research institutes provide a way to leverage different types of government and nongovernment resources; and different scientific and engineering disciplines, to address critical medium-term aquaculture industry needs on a pre-competitive basis. Testbed facilities and pre-permitted incubators to conduct industry relevant scale and pre-commercial testing are also facilitated by a national lab or other stable funded, long term program with key infrastructure (Table 3), anchoring a consortium approach. The list of areas to which this could be applied is long and includes: hatchery and larval bottlenecks for all types of organisms, offshore R&D projects to test gear types, feeds development and demonstration sites for numerous technology types, and seafood science. These are only a few examples that may benefit from medium-term R&D partnerships targeting key areas ripe for development. While these types of institutions can be highly productive, they also require a critical mass of resources to establish that needs to be committed for a longer term than the federal budget cycle, and they may have additional overhead. For these reasons, NOAA has not made extensive use of these types of institutes.

Measurement of success across all Science Assets

NOAA's research to application (R2A) performance should provide clear direction to researchers, reward project advancement and quantify research progress. The difficult task of tracking impact is an important function, helping to ensure efficient transition of research advances to commercial or other applications. At the same time, tracking success should not be defined solely in terms of technology transferred. Well-researched dead-ends can be more valuable than poorly investigated home runs. Complicating measurement is that science does not produce strait line predictable progress from research to development.

Developing research to application (R2A) performance measures may help put the latest innovations in the hands of stakeholders empowering them in support of a growing domestic marine aquaculture industry. The America COMPETES Act (2011) required NSF to contract with the National Academies (NAS) for a study to evaluate, develop, or improve metrics for measuring the potential impact of research on society. Among other things, the act asked the NAS to evaluate the "potential for commercial applications of research studies funded in whole or in part by grants and financial assistance from the Foundation or other Federal agencies". In its reply[14], the NAS highlighted several points related to measurement of impacts from federal research spending:

- "Currently available metrics for research inputs and outputs are of some use in measuring aspects of the American research enterprise, but are not sufficient to answer broad questions about the enterprise on a national level.
- The impacts of scientific research can best be determined not by applying traditional metrics such as counts of publications and patents, but by cultivating an understanding of the complex system that is the U.S. research enterprise to determine how all of its component parts interrelate.
- Ongoing data collection efforts (on funding to innovation) could potentially be of great value if these data sets could be linked with other data sources and made more accessible to researchers."

One such data collection effort is outlined in Administrative Order (NAO) 216-115: Strengthening NOAA's Research and Development Enterprise[15]. This Administrative Order calls for all of NOAA's science enterprises to track and report on the degree to which NOAA's science funding is resulting in end uses important to society. NOAA is in the process of developing an enterprise wide database (NOAA Research and Development Database – NRDD) with associated performance measures used to evaluate progress toward achieving objectives. Performance measures and milestones will be monitored over time and reported periodically. The intent is

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[14] National Research Council. (2014). Furthering America's Research Enterprise. R.F. Celeste, A. Griswold, and M.L. Straf (Eds.). Committee on Assessing the Value of Research in Advancing National Goals, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

[15] https://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-115A.html

that this will provide a measure of whether work done is achieving desired outcomes on schedule, and serve as an early warning system to identify the need for adjustments.

To be useful for on-going strategic management this information should be structured to understand interdependencies among performance targets, scientific assets and the larger scientific landscape. This information could also aid understanding the resource requirements and risks of not resourcing a capability. Appendix 2 outlines a draft request to PIs (internal and grant-funded by NOAA) to provide information needed to populate the NRDD. Longer term, this information can help management to consistently monitor and foster innovation resulting from diverse scientific approaches.

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An Example – Development of alternative feeds for Aquaculture (Set in sidebar with a photo)
Numerous examples illustrate the strength of the "all-hands-on-deck" approach, in which long-term programs (typical of national labs) support and are supported by short-term projects (typical of grant programs and industry projects) with the ultimate result of moving pre-competitional research and development from public funding to foundation and private funding. The development of alternative feed[16] ingredients for raising fish on farms, in the United States provides a good illustration. The particular success in this area is not due to any one approach or institute, but rather taking full advantage of the strengths of all types of programs and projects from various institutes.

Long-standing programs in fish nutrition are located in two national labs, one belonging to USDA ARS (Boseman, MT) and one belonging to NOAA (NW Fishery Science Center, WA). Past work in these labs, and by university, NGO and industry researchers combined to develop a rich foundational literature on multiple aspects of fish nutrition, physiology and feed manufacture. This body of research was critical to have in place for successful industry development to occur[17]. In 2005, USDA, NOAA, the soybean association, and other partners established a joint effort[18] to respond to growing concerns over increasing use of limited forage fish for aquaculture feeds[19] and to provide strategic direction in developing alternative feed ingredients. Work at the national labs and at many academic programs funded by NOAA and USDA grant programs all contributed to demonstrating that diets containing no fishmeal or fish oil perform as well as conventional diets[20].

A key to achieving these results were unique facilities and equipment at the USDA's aquatic animal feeds lab and NOAA's marine labs and the professional technical expertise that only comes from years of operating these facilities. Grant funded researchers were able to take

[16] feed not based on wild forage fish.

[17] Indeed, in an NRC report to Congress on innovation, the need for basic science is called out as a prerequisite for innovation. While NOAA does not invest in basic research, a connection to it is critical. NRC 2017.

[18] See: https://www.fisheries.noaa.gov/noaa-usda-alternative-feeds-initiative

[19] See: https://www.tandfonline.com/doi/abs/10.1080/10641260802677074?journalCode=brfs20

[20] See: http://magazine.fishsens.com/usda-researchers-develop-all-vegetarian-fish-feed-to-help-aquaculture.htm

advantage of the USDA national lab facility to make various industry relevant experimental diets that eventually extended success to numerous aquatic species and with multiple formulations using a wide variety of ingredients. Recently, private and foundation funding has taken over much of the research to develop alternative fish feed ingredients. The soy industry for example spends approximately $1M a year on studies to improve the utilization of soy in aquaculture feeds[21]. Soy is now the largest single ingredient used for aquaculture feeds worldwide, and the US soy industry is a major supplier. The importance of agriculture to aquaculture will likely increase as investment by agro-business is developing oil crops with high levels of long chain omega 3 fatty acids[22] to address fish oil replacement. This example illustrates the power of successful creation and delivery of scientific advancements for aquaculture, and the need for complementary national labs and grant programs. Start-ups targeting aquaculture feeds are now producing feed ingredients from insect meal[23], single cell proteins[24], processed food waste[25], recycled fish trimmings,[26] marine algae, and other ingredients. Time will tell how many of these will have a success story similar to soy, but the explosion of economic activity on finding a plethora of environmentally friendly feed ingredients is already occurring.

Recommendations to create conditions for innovation

NOAA can best create the conditions needed for innovation in aquaculture by increasing its access to at sea growout capacity. The facilities at Manchester and the collaborative arrangement with UNH are valuable but limited resources, especially if development of nearshore and offshore aquaculture in Hawaii, the Gulf of Mexico or S. Atlantic waters is envisioned in the future. It is probably reasonable to say that development of marine finfish aquaculture in the U.S. is not limited by lack of hatchery know how or fish health and nutritional expertise, but by lack of access to coastal waters in which to establish farms and how best to use them and determine environmental impact.~~....~~

Advances in innovation may include the combination of the right mix of expertise, infrastructure and resources.

A~~Consider referencing~~ DARPA and NOAA Aquaculture model –would open the door for innovative ~~for ideas related to innovation and~~ high risk projects that will assist in advancing the US aquaculture producer community.

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[21] See: http://www.soyaquaalliance.com

[22] See: https://www.undercurrentnews.com/2018/02/08/crops-will-become-cheapest-new-source-of-omega-3-fatty-acids-cargill-says/

[23] See: https://thefishsite.com/articles/insect-meal-gains-us-fish-feed-approval

[24] See: https://www.feednavigator.com/Article/2018/01/19/KnipBio-ups-production-of-single-cell-protein-feed-products-for-aquaculture

[25] See: https://www.sciencedirect.com/science/article/pii/S0269749116305231

[26] See: https://www.nwfsc.noaa.gov/research/divisions/efs/aquaculture/feeds/meal_process.cfm

Table 2. Characteristics of NOAA's Scientific Assets.

Attribute	**Grant Programs**	**National Labs**	**Extension/ Coordination**	**Challenges/Prizes**	**International Science Agreements**
NOAA Vision Statement(s)		A. We will develop NOAA science Center Assets into leaders in aquaculture research and development by investing in infrastructure and programs that take advantage of their long-term nature. B. Science Centers will become a stable hub to leverage grant, international and industry research to develop marine aquaculture that improves the economic, environmental and social performance of the industry.	We will integrate extension and coordination with end users in all aspects of NOAA's Aquaculture Science.	We will explore the use of Prizes to engage a unique and non-traditional set of individuals and organizations to offer novel solutions for important issues limiting growth of national marine aquaculture.	A. We will utilize international science agreements to leverage and improve domestic resources and expertise needed to develop and manage a world class marine aquaculture sector for the US and abroad. B. International Science Agreements will augment and leverage Science Center, grant, and industry research to develop marine aquaculture that improves the economic, environmental and social performance of the industry, nationally and globally.
Time frame	Short term – grants from 1-5 years	Long Term – Programs can run decades	Long Term – length of a career or more	Short – 1-3 years	Agreements are long term, projects are typically short term.
Scale/Diversity	Small to medium/Lots of topics	Small to Pilot Commercial/ Fewer topics	Small to Commercial – Fewer topics than grants	Small/Highly targeted	Small/lots of Topics
Personnel	Highly diverse. Researcher/Educator, Students and Extension. Specialists to generalists	Professional Researchers and Technicians. Less diverse.	Professional Extension Agents and Coordinators – Generalists	Industry and Academia	All types
Strategic direction	Bottom up more important than top down – Projects proposed by PIs	Top down more important than bottom up – Projects developed by both PIs and budget holders	Bridges Top down and Bottom up goals	Mixed – Topic is narrow and top down, innovation is bottom up.	Variable
Accountability of research to Federal goals	Medium	High	Medium to High	Variable	Low

Attribute	Grant Programs	National Labs	Extension/ Coordination	Challenges/Prizes	International Science Agreements
Ability to support key infrastructure [27]	Difficult to justify without program funding from another source. Can help programs with variable funding from States and foundations	National labs can be organized around key enabling infrastructure, test beds and/or expertise clusters	Often opens up use of private, university or nonprofit facilities for research	No	No
Major Strengths	• Able to change goals quickly - nimble • Able to bring in expertise outside of the field easily • Education component to address workforce needs • Relatively easy to scale to resources • Ability to leverage funding by requiring a "match" • Ties to more basic research and extension service impacts entire value chain	• Outputs from larger scale projects can provide non-science products to others[28] • Can be designed so that science advice meets requirements under the IQA[29] or uses sensitive data. • Supports key long-term program areas with science and products at relevant scale • Able to support key infrastructure such as hatcheries, feed production, and test-beds • Provides long term national and regional focus • Builds expertise for policy advice and grant reviews • Cares for long-term data sets, IT, and collections (algae, genetics, monitoring data, unique samples)	• Proven track record of getting science transitioned to use. The importance of this cannot be overstated • Improves focus of science on to topics needed by society • Provides connection among all players from science to end use • "On-farm" research	• Engages non-traditional innovators that offer new perspectives and novel solutions to overcome important barriers and support growth of domestic marine aquaculture. • Used extensively by other federal agencies, therefore the process, infrastructure, network of services and resources of support are well developed. • Reaches hundreds of thousands of self-selected individuals and organizations that, to this point, have been an untapped resource different from those attracted by usual contracts or grants. • Seeks out and highlights innovative ideas that haven't been applied to aquaculture.	• Leverages US resources with expertise and in-kind funding. • Helps US researchers and managers stay up to date with world advances and issues • Provides research on industries that have already developed elsewhere allowing for the US to benefit from what went right and avoid what went wrong • Expands the breadth of issues to address multi-societal concerns (e.g. animal welfare) • Builds worldwide expertise for policy advice and grant reviews • Allows investigation of trans-boundary issues • Improves focus on common issues • Aligns industry performance and standards to encourage

[27] For example: ships, permitted offshore sites, hatcheries, feed mills, large systems, selected broodstocks, collections, expensive lab equipment, etc.

[28] For example: fingerlings, feeds, genetic material, algae starters, long term data sets, models etc.

[29] Information Quality Act. Scientific advice used for many government regulations has additional due diligence requirements not typically dealt with outside of government labs.

Attribute	Grant Programs	National Labs	Extension/ Coordination	Challenges/Prizes	International Science Agreements
		● Provides timely (annual) data updates for management models dependent on recurrent data ● Offers opportunities for public partnerships with other research organizations and industry such as through CRADAs		● Leverages funding from applicants. ● Offer a new mechanism to engage stakeholders. ● Applying challenges to aquaculture is a new approach that is consistent with crowd sourcing strategies that have been successfully applied to other areas of society.	trade – raises the bar for everyone. ● Offers a unique experience with exposure to other cultures, practices, and needs ● Improves access to critical mass and key skill sets lacking in the US ● Facilitates access and benefits sharing ● Allows U.S. to promote and help in developing environmental standards with other countries that will level the playing field with U.S. producers
Types of science best used for	● Diverse, cutting-edge high-risk research ● Basic and applied research more or less equally ● Emerging areas ● Bringing in technology from outside the sector ● Special topics research ● Highly specialized research	● Government advice integration and synthesis ● Regulatory tools and decision making ● Pilot and small commercial scale research ● Long term science needs or reoccurring science products[7] ● Majority applied, minority basic	● Bridges science and application for both regulatory tools and industry needs.	● Very close to market or end use.	● All types ● Need for long term connection to science managers among countries as needs and topics change

Table 3. Examples of key enabling infrastructure (excludes private facilities)

Type of Infrastructure	**Federal Lab**	**University/Non-Profit or Other**
Hatchery (Shellfish)	• NEFSC Milford Lab (P -Oysters, Mussels) • NWFSC Manchester Lab (P Oysters, Clams, Abalone and others) • SWFSC La Jolla Lab (R -Abalone)	• VIMS • OSU • LSU • UM – Horn Point • FAU Harbor Branch Oceanographic Institute (Clams)
Hatchery (Finfish)	• NEFSC Sandy Hook Lab (R- Winter Flounder and others) • NWFSC Manchester Lab (P -Sablefish and others)	• Hubbs- Seaworld Research Institute, San Diego (P- Seriola, C – White Sea Bass, R – California Halibut) • University of Southern Mississippi • University of Miami • North Carolina State University • FAU Harbor Branch ~~Research~~ Oceanographic ~~Research~~ Institute (Warm Water) • Mote Marine Laboratory
Nursery (Seaweed)	• NEFSC Milford Lab (R- Sugar Kelp) • NWFSC Manchester Lab (P- Sugar Kelp, Turkish Towel and others) • AKFSC Kodiak Lab (C- Sugar Kelp)	• UCONN • FAU Harbor Branch Oceanographic Institute (Ulva and Gracilaria onshore in IMTA)
Feed Production/Nutrition	• NWFSC Montlake Lab (R- extrusion, P - compaction and pre-processing) • USDA Bozeman	• Texas A&M • University of Idaho, Aquaculture Research Institute
Grow-out facilities	• NWFSC Manchester Lab (P- Net pens)	• UNH Offshore Site • FAU Harbor Branch Oceanographic Institute (onshore RAS for marine warm water finfish)
Reference Labs	• NSIL (C -Reference lab services commercial testing labs)	• FAU Harbor Branch Oceanographic Institute (Aquatic Animal Health Lab)
Unique or long-term Data Sets	• NOS Beaufort Lab (C – MSP and other tools/Tool box) • SWFSC La Jolla Lab (Calcofi) • NOAA Office of Science and Technology - Statistics annually reported in Fisheries of the United States	•
Seafood Products/Forensics	• NSIL (???) • NWFSC (P – Pilot plant, C - Forensics)	• University of Florida, Aquatic Food Products Lab
Genetic selection programs	•	•

Type of Infrastructure	Federal Lab	University/Non-Profit or Other
Genomic tools and resources	• SWFSC • NWFSC	•
Test Beds/ Demonstration sites	•	• UNH Offshore Site • FAU Harbor Branch Oceanographic Institute (Aquaculture Development Park)University of Florida, Shellfish Extension
Engineering Facilities	• USNA? (Wave Tank?)	•
Physical, chemical and biological ocean observation	• Integrated Ocean Observing System	• 11 Ocean Observing System Regions
Other	•	•

Please indicate if facilities are at R = Research Scale, P= Pilot Scale or C= Commercial Scale, and species or importance of asset.

Section 2. Topical foci for NOAA's Science Assets

Vision: Facilitate understanding of key science areas leading to the development and integration of aquaculture within the ecosystems of U.S. waters in a way that promotes resiliency and maximizes benefits to interlinked social, economic, and ecological systems.

Section 2 is structured by scientific disciplines. Each subsection has one or more vision statements which are meant to be aspirational. Each section also contains bullet lists of benefits if the visions were to be realized in terms of environmental, economic and social bottom lines. Finally, each section has a list of key infrastructure needs, and a research approach to address the visions. The topics, vision, and benefits statements, were developed from previous plans (Table 1) and were added to by the Aquaculture Task Force of the Marine Fishery Advisory Committee, NOAA's Regional Aquaculture Coordinators, Office of Aquaculture Staff and the literature. NOAA's research portfolio is also informed by, and responsive to the laws as listed in Table 4.

Scientific Discipline: Genetics

Vision:

- Operationalize a framework for genetic risk assessment and management that includes realistic science-based expectations for implementing genetic improvement programs, particularly selective breeding while minimizing risk to wild populations from escapes.
- Use state of the art genetic tools for marker-assisted selective breeding program(s) for fish, shellfish, and seaweeds to improve competitiveness, improve disease resistance, and address health issues.
- For species which present a high genetic risk from escapees, be able to produce low cost sterile animals for culture or other management approaches.

- Scientists liaise with industry to coordinate trait selection and to discuss legacy provisions for selected brood stock.

Key Benefits

Environmental

- Reduces the genetic risk of escapes to wild stocks.
- Increases resilience in the face of climate change by selecting progeny that will survive under certain conditions.
- Informs environmental decision-making and policy development.
- Decreases pressure on natural resources directly (reduced fishing pressure), through enhancement efforts, and by limiting inputs (excess feed, disease transfer and excess therapeutants, fish waste, etc.), e.g., when fish convert feed better there will be less impact on the environment from excess waste and nutrients.
- Enables exploration of concepts like the genetic rescue of functionally extinct populations.

Economic

- Improves financial performance by increasing survival, growth rates and food conversion efficiency.
- Increases resistance to disease and tolerance of alternative feeds and selected environmental conditions (thermal, density, pH, etc.), which reduces reliance on therapeutants and traditional feeds made from fishmeal and fish oil.
- Supports granting of licenses to operate.
- Enhances the push toward hatchery development, which is needed to support the growing industry that needs robust fingerlings.
- Fosters technological innovation from the science side.
- Enables multi-sectoral job creation and facilitates resource sharing in a microeconomic context.

Social

- Increases seafood resiliency and food security in the face of climate change.
- Provides a nutritious, consistent (quality and quantity), and affordable sources of protein (offer products at a lower cost).
- Secures jobs and job retraining opportunities for growth of the industry.
- Contributes to supporting, provisioning, regulating, and cultural ecosystem services.
- Improves animal welfare by reducing morbidity and mortality due to disease susceptibility, heritable disability, and adverse hatchery environmental conditions.

Key infrastructure needs (To be added by scientists)

- Hatcheries
- Broodstocks
- Information/samples of wild stocks
- Genomic laboratories and Sequence Databases

Research Approach (To be added by scientists)

- Develop easy to use, transparent tools to integrate genetic guidance and, genetic risk assessment, and development of specific genetic risk avoidance and mitigation strategies for mangers. Then use these tools to allow development of low risk species and develop further risk mitigation tools for high risk species.
- Encourage comprehensive baseline research studies across a range of current and candidate aquaculture species as well as their wild relatives, including but not limited to:
    - Spatiotemporal population genetic structure and diversity
    - Stock synthesis modeling and stock assessment
    - Habitat, ecological, and species demographic field surveys
    - Fisheries-dependent and -independent mark-recapture surveys
    - Hatchery genetic and genomic pedigree tracking
- Identify and domesticate the gene complexes that drive physiology functions to improve husbandry and product quality, improve shelf life of shellfish as an example.
- Genetics, Nutrition and Physiology are explicitly linked and multidisciplinary research results in improved performance.

Scientific Discipline: Aquatic Organism Health/Pathology

Vision (s)

- A world class aquatic animal health management program supporting marine aquaculture and wild aquatic organisms by minimizing disease risk through prevention and treatment.
- NOAA in coordination with USDA-APHIS and FWS provides world-class research and risk assessment and epidemiological tools that informs strategies for the control and containment of infectious marine aquatic animal and plant pathogens.

Key Benefits

Environmental

- Decreased use of antibiotics and chemicals.
- Decreased likelihood of spreading disease or parasites from the farm to the wild.
- Decreased impact of pathogens of cultured fish interacting with wild fish.
- Increased potential of success for enhancement programs.

Economic

- Reduced cost of production because prevention is much more cost effective than treatment through:
    - Cost effective vaccine delivery methods, farm-level field diagnostics, and husbandry practices.
    - Rapid communication of recommended actions/treatments.

        - Survival levels increase, resulting therefore in better FCR's, cleaner operations and more farm capacity from the same hatchery output.
        - Opportunities for new diagnostic and treatment products, biological, mechanical and chemical.
    - More rapid availability treatment methods through streamlined process for approval of (and access to) new antibiotics and other innovative treatment regimes.
    - Reduced costs and increased profits and more jobs.
    - A certified Fish Health Program promotes market development.

Social

- Improved animal welfare in the hatchery and on the farm.
- Consumers can trust US cultured product is raised responsibly, with due regard for environmental health and consumer health, and fish welfare.
- On farm animal welfare is important and public can feel good about how the animal is cared for.
- Pride by growers, sellers, and consumers in US methods for producing product.
- Treatment programs that do no harm to the environment.

Key infrastructure needs (To be added by scientists)

Research Approach (To be added by scientists)

- Focus is on pathogens that pose a threat to marine aquaculture, especially those pathogens that:
    - Occur in wild reservoir hosts and may be transferred to marine aquaculture.
    - Occur in marine aquaculture and may be transferred to wild stocks.
    - Those pathogens that may be introduced from exotic sources.
- Improve procedures for certification of products that are produced by best disease prevention practices, including:
    - Specific-pathogen-free certified stocks.
    - Farm siting program that addresses likelihood of pathogen outbreaks and spread.
- Develop certified best practices for preventing and addressing outbreaks of pathogens.
    - Including treatment (better chemical treatments [including antibiotics].
    - Prevention (vaccines and site selection).
    - Depopulation methods if necessary.
- Develop biological solutions for parasite control, such as cleaner fish husbandry programs.
- Develop selective breeding programs to produce more resistant strains to known

pathogens.
- Research to support the FDA drug approval process for marine organisms. Develop clear process for drug approval prioritization and work with DAWG to add marine organisms to target species groups

Scientific Discipline: Oceanography/Marine Spatial Analysis

Vision (s)

- Widely available low-cost site analysis and industry performance tools for both regulators and farmers looking at potential farm sites and management options driven by reasonably priced, robust, web accessible or data logging environmental monitoring equipment and oceanographic models (data).

Key Benefits

- **Environmental**
    - Appropriate site selection of farms to reduce the potential for negative environmental impacts and user conflicts.
    - Improved management of marine aquaculture
    - Increased understanding of oceanographic conditions in open ocean environments.
    - Better understanding of the actual distribution of and potential environmental impacts of commercial activities.
- **Economic**
    - Reducing the cost and improve the quality of site characterization by planning ahead.
    - Better site selection and improved confidence in the decision-making process, leading to reduced environmental, regulatory, system failure risk and human capital (time and resources).
    - Site specific systems engineering leading to reduced cost and greater operational efficiency.
    - Potential reduction in anchoring and fixed costs due to colocation with other enterprises such as wind farms.
    - More efficient aquaculture husbandry and production due to ideal site selection and better industry management.

    - Improved efficiency will also be driven by selection of efficient aquaculture species. Especially this means species that adapt well to farm conditions, grow quickly to market size and yield a high percentage of edible meat on their frames.

- **Social**
    - Reduced social conflict with other ocean users including commercial fisheries due to accurate spatial data on distribution of other users in advance of selecting sites and permit submission.
    - Reduced concern about environmental impacts due to increased monitoring and ~~more~~ effective site selection.
    - Increased worker safety due to appropriate site selection and site-specific engineering design.

Key infrastructure needs (To be added by scientists)

- Dedicated computer resources
- Access to data
- Real-time access to ocean observing data.

Research Approach (To be added by scientists)

- Spatial use conflicts between commercial fisheries, fishing activities, Navy, or other national security activities and aquaculture site locations, prior to permit submissions, have been reduced (prior to permit submissions) through improved national spatial mapping of coastal, marine areas, and land areas for aquaculture.
- Fine scale description of benthic conditions, wave height, and wind velocity dataset in areas of potential offshore aquaculture development.
- Fine scale description (maps) of benthic conditions and habitats depicting essential fish habitat, habitats of particular concern (EFH and HAPC, both for managed fisheries), and critical habitat designations (for protected resources), with levels of risk defined for different habitats.
- Forecasting harmful algal blooms and how to protect farms from these risks
- Integrate real-time ocean observing data with farm site analysis.

Scientific Discipline: Economics and Statistics

Vision (s)

- NOAA will be able to assess the economic impact and economic potential of marine aquaculture for all areas of the country
- NOAA's national marine aquaculture statistics will be the preeminent source of data for all stakeholders. Comprehensive, accurate and timely information will effectively inform

science, regulatory and outreach efforts that support a growing domestic marine aquaculture industry.

Key Benefits

- **Environmental**
  - Increased environmental regulatory efficiency.
  - Identification of potential environmental impacts most amenable to cost effective reduction and/or mitigation.
  - Economic models or enterprise budgets for place-based species.
- **Economic**
  - Identification of opportunities for increased regulatory efficiency and reduced regulatory costs.
  - Inclusion of economic incentives in a comprehensive Aquaculture Economic Development Plan (AEDP).
  - Benchmarking would allow improved access to financing and possibly insurance.
  - Selection of species for domestication based on market characteristics (e.g., edible meat yield, price, product, place, promotion) not just biological characteristics.
  - Industry trade-off analysis
- **Social**
  - Comprehensive AEDP to provide a roadmap for aggressive development of domestic aquaculture sector, increasing employment, decreasing trade deficit and providing a superior product.
  - Improved understanding of where management agencies limited resources should be invested for best ROI.
  - Reduced risk of financial failure of public/private demonstration projects that will lead to commercial enterprises for the communities.
  - Produce species that are affordable for the consumer, ~~.~~which means that they must adapt well to farm conditions and yield a high level of edible meat. A yield above 50% is desirable.

Key infrastructure needs (To be added by scientists)

- ***Economic model templates for building production, marketing and production plans***
- ***App that has real time data to keep up to date statistics on growth of the aquaculture industry – adds new businesses that come on line***

Research Approach (To be added by scientists)

- Develop marine aquaculture modules for the IMPLAN model, and integrate aquaculture into other economic research conducted by NMFS.

- Systematic analysis of the economic development tools (e.g., tax incentives, training programs) necessary to incentivize offshore aquaculture development.
- Determine an accurate accounting of the cost of regulatory compliance for domestic aquaculture producers.
- An objective cost benefit analysis of domestic seafood production including all management costs, environmental externalities and resulting mitigation costs, tax incentives and emergency relief program costs.
- Species and production method specific economic benchmarking studies to track production timing and output.
- Species specific market studies that improve our understanding of demand curves, product form, price elasticity and sensitivity, and market locations.
- Trade off analysis to optimize benefits
- Link the investments made by DOC and others in the science and technology needed to develop sustainable marine aquaculture to other parts of DOC charged with economic and business development.
- Add Aquaculture to Fisheries Economics of the US.
- "One-stop shop" for entrepreneurs to locate business opportunities/information for aquaculture ventures.
- Improve the collection and reporting of annual aquaculture production statistics to be complete and accurate.

Scientific Discipline: Physiology

Vision (s)

- Understand the physiological basis to increase efficiency and reduce risk in order to expand aquaculture production of finfish, mollusks, crustaceans, and macroalgae.
- Egg to egg understanding that optimize the genetic potential of all aquaculture organisms

Key Benefits

- **Environmental**
  - Reduced environmental nutrient inputs through understanding the physiological response of organisms to feed formulations and selection programs to improve assimilation of nutrients.
  - Reduced risk for genetic and disease impacts through incorporation of sterilization or monosex production technologies
  - Reduced resource waste by selecting species that thrive under farm conditions, produce a high percentage of edible meat, and by good farm operation and

management ~~maximizing organisms'~~ performance

- **Economic**
    - Increase farm gate revenue/profit margin through improved production efficiency and reduced feed/operating costs.
    - Increase revenue enhancing physiological traits that through manipulation will maintain/enhance growth and survival while facing climate related environmental changes.
    - Increased resiliency
- **Social**
    - Provide fresh, low carbon footprint domestically farmed seafood for American consumers.
    - Minimize operations that cause stress or impact on farmed organisms and improved animal welfare.
    - Strengthen coastal economies through diversification and expansion of the aquaculture sector.
    - Increase knowledge in local communities and beyond of the need for, and sustainability of farmed seafood as the industry grows.
    - Increased seafood consumption promoting health and well-being that will reduce health care costs and improve quality of life.

Key infrastructure needs (To be added by scientists)

- …

Research Approach (To be added by scientists)

- Reproductive performance
- Monosex and sterility.
- Larval survival and health to produce high quality eggs and larvae.
- Nutrition-physiology interface to improve performance on feed
- Growth rates and disease resistance.
- New species with production potential, capable of meeting economic projections under farm conditions, in other words - survive and grow well under ~~stressful~~ well managed culture conditions~~ - stress physiology~~.
- The ability of farmed aquatic plants and animals to adapt to changing environmental parameters as the climate changes
- Genetics, Nutrition and Physiology are explicitly linked and multidisciplinary research results in improved performance.
- Understand trade-offs between environmental optima and physiological

performance.

Scientific Discipline: Engineering

Vision (s)

- Use engineering technology to ensure robust marine aquaculture system performance at reasonable costs that maximize the culture organism's production potential, worker safety and economic performance while minimizing labor needs and impacts on wild organisms.
-

Key Benefits

- **Environmental**
    - Reduced risk of systems failure to mitigate environmental impacts and economic losses.
    - Improved site selection and environmental monitoring.
    - Improved animal welfare and health condition leading to reduced disease risks.
    - Coastal and offshore ecosystems benefit due to aquaculture infrastructure nurturing fish and invertebrates.
    - Reduce negative impacts to wild organisms.
- **Economic**
    - Improved, specific modeling work by manufacturers, as well as modeling by the research community for improved and cost-effective equipment.
    - Increased labor efficiency and reduced production costs. This may include expanded use of artificial intelligence.
    - More efficient use of capital and operational expenses to increase ROI.
- **Social**
    - Increased worker safety.
    - Increased domestic aquaculture production with reduced trade deficit.
    - Increased number of jobs and ancillary business which support aquaculture sector (e.g., sensors, cages, remote maintenance and feeding)

Key infrastructure needs (To be added by scientists)

Research Approach (To be added by scientists)

- Appropriately designed, reasonably priced equipment and facilities for all types of systems (e.g., high energy offshore sites, coastal sites, fish ponds, and land-based systems).
- Cost effective remote sensing and monitoring systems for offshore farms.
- Production systems that maintain animal welfare while reducing the need for on-site

personnel, including through the use of remote monitoring.

- Definition of welfare indicators that can be observed by those working with the culture species and/or by remote sensing and monitoring systems.

- Cost effective mooring systems for deep water sites.
- Stock and equipment handling systems for large scale offshore farming systems.
- Development of systems for co-location of renewable energy and aquaculture.
- Labor-saving devices and equipment for shellfish culture.
- Evaluation of wave attenuation by floating shellfish gear to estimate the value of ecosystem services associated with erosion prevention.
- Reduce entanglement risk potential for marine aquaculture structures
- Develop systems that are less dependent on fossil fuel use, which will decrease greenhouse gas emissions.
- Use of drones for surveillance, collection of data, collection of water samples, forecasting HABs, etc.

Scientific Discipline: Environmental/Ecosystem Services Science

Vision (s)

- Understanding of how aquaculture can enhance ecosystem services and provide resiliency is advanced to the point where it can be operationalized. This includes:
    - Defining the habitat value of all types of aquaculture
    - Presenting no risk of entanglement or injury to protected resources
    - The potential effects from environmental/climate change in all geographic zones in the U.S. has been modeled, including spatial planning, for aquaculture purposes. The stakeholders use this information to make wise decisions on what species to farm, selective breeding programs, what systems to use, and where to locate their farms.
    - There are strains of aquaculture species that are adaptable and resilient to different climate events and are low risk for wild stock; these strains provide the farmers with a way to grow a secure seafood supply.
    - The aquaculture industry is an activity that demonstrates low impact on the environment by growing protein sources that have a lower carbon footprint compared to its counterparts.
    - Resource manages encourage aquaculture industries to locate in certain sites to improve environmental quality in a body of water (e.g., balance nutrients), add habitat and/or to mitigate ocean acidification.

Key Benefits

- **Environmental**
  - Enhanced Ecosystem services from Aquaculture
  - Increased environmental resiliency in the face of climate change
  - Expand on the development of economically feasible systems that work with the environment (Ecosystem Approach to Aquaculture).
  - No entanglements
  - Increased habitat
  - …
- **Economic**
  - Increased aquaculture businesses that provide ecosystem services and also produce a product for sale (e.g., seaweeds and shellfish)
  - Use strains of fish, crustaceans, mollusks and seaweeds that are adaptable to changing conditions (e.g., temperature, low pH) to ensure a steady supply of safe seafood.
  - Improve insurability of the farms that are affected by environmental changes and natural disasters.
  - Increase opportunity for payments for ecosystem services for nutrient or carbon capture (and other ecosystem services) provided by aquaculture.
- **Social**
  - Secure seafood and other products in a changing environment
  - A more resilient healthy wild ocean ecosystem

Key infrastructure needs (To be added by scientists)

Research Approach (To be added by scientists)

- Study the habitat implication of aquaculture. Aquaculture can provide habitat to enhance fisheries and to expand ecosystems. It would be a helpful research topic to better understand the level of risk and benefits associated with different aquaculture activities for different habitat types. This is what is needed for industry applying for sites and to know whether we are doing well as a society to protect and conserve these resources and sites.
- Climate change adaptation needs to start with an accurate assessment of current climate variability in different climate and geographic zones in the US and relate this to onshore and offshore aquaculture. Forecast models can be developed for these zones to determine how short-term and long-term changes in conditions can affect aquaculture farms. This will provide the farms a level of how to be prepared or adapt to these changing conditions. We also need to map pest, parasites and pathogens in relation to climate change zones and how these will shift with changes in the environment and how they will affect the aquaculture species grown in those zones

- Couple resiliency assessment with vulnerability assessment
- Study phytoremediation with seaweeds to reduce the CO_2in the water (halo effect) and produces an edible product. Growing shellfish in this halo area is also beneficial for shellfish production. (reference: Bigelow Laboratory)
- Investigate the low carbon impact of growing seafood protein and how aquaculture can mitigate environmental issues such as ocean acidification through carbon sequestration.
- Work with stakeholders to develop an integrated and coordinated science-based approach to prevention and mitigation actions. This can be done for instance by developing a good biosecurity plan to understand how to mitigate known pathogens that might emerge due to environmental change. As part of the biosecurity plan include outreach that ensures that consumers know that the health and food safety of the aquacultured farmed products are not being jeopardized when there are environmental changes and/or natural disasters.
- Mitigating acidification impacts with extensive seaweed culture and the use of buffered seawater in hatcheries.
- Breeding selected lines of acidification-resistant corals and shellfish.

Scientific Discipline: Social Science

Vision (s)

- Operationalize public-private[30] programs, interactive networks, and messaging to build consumer confidence in farmed seafood by increasinge~~e~~ public awareness and understanding (i.e., social license) of farmed seafood production and consumption.
- We envision an aquaculture industry that is able to expand its operations to fulfill its potential, within ecosystem carrying capacity limits of the waters in which it operates, and that is a welcomed, integral part of the coastal communities, where it is appreciated for the economic and nutritional benefits that it brings, and that works to ensure that environmental or other impacts are beneficial, minimal, or mitigated.

Key Benefits

- **Environmental**
  - Reduced environmental effects, footprint, and regulatory costs.
- **Economic**
  - Improved and expanded seafood availability and affordability.

[30] Aquaculture, fishery, professional (human or animal health and nutrition), environmental and consumer organizations; public (Land and Sea Grant) and private universities; local, state and federal governments; and seafood wholesale, retail and food service businesses.

    - New and expanded non-farm services and suppliers, on and off-farm managerial, skilled and unskilled jobs, and increased economic resilience for rural inland and coastal communities and urban food deserts.
    - New or expanded aquaculture technical training and undergraduate and graduate training in aquaculture centers and laboratories at community colleges, universities, tribal and other research facilities.
- **Social**
    - Objective, science-based chemical, biological and physical risk analyses to inform seafood safety and inspection, public appreciation for the benefits and risks associated with farmed species that are genetically modified (i.e., transgenic or gene edited), and the regulated use of approved aquatic animal medicines.
    - Improved public perception of farm environmental stewardship and federal, state regulatory structures (laws, regulations and agencies) and the means to govern offshore marine farming by utilizing contract law (i.e., lease).
    - Improved public appreciation and understanding to inform and increase the selection, purchase, preparation, and consumption of seafood.
    - Improved human nutrition, health and well-being that will reduce health care costs and improve quality of life.
    - Communicate to the global community an example of holistic aquaculture governance (ecological, social and economic).

Key infrastructure needs (To be added by scientists)

Research Approach (To be added by scientists)
    - Objective, science-based biological, ecological, geophysical and economic risk analyses to inform the governance of farm size, siting, construction, operation and maintenance and the opportunity to culture species not native to a farm location or transgenic/gene edited species.

Scientific Discipline: Nutrition

Vision (s)
- Research will provide feed manufactures with numerous choices in feedstuffs suitable for marine aquaculture production, decrease the cost of, and maintain or improve the human health value of cultured seafood.
- Feeds will be available for all life stages of target organisms that result in high performance.
- ~~......~~Feeds will be available in suitable formats to minimize wastage by the cultured

species and to increase efficiency of feed conversion

Key Benefits

- **Environmental**
  - Reduced environmental nutrient inputs through tailored feed formulations and programs to improve digestibility of feeds and assimilation of nutrients.
  - A variety of feedstuffs adds resilience in the whole fed aquaculture sector
  - Providing a market for seaweeds as feed will encourage their production, decreasing eutrophication and the effective trophic level of farmed fish.
  - Increases food at lower environmental footprint than land animals
- **Economic**
  - Feeds are the highest cost part of fed aquaculture. Improved feeds will lower costs
  - Provides market for terrestrial agriculture linking farming and aquaculture
- **Social**
  - Maintain health benefits of seafood consumption by development of omega 3 rich diets
  - Provides link between coastal communities and inland areas.

Key infrastructure needs (To be added by scientists)

- Feed mills at a scale and type to be commercially relevant – ie extrusion.
- Feeding systems for various species (replicate tank systems)
- Specialized equipment and systems for larval stages of fish and shellfish
- Large replicate tank systems for broodstock studies

Research Approach (To be added by scientists)

- Studies on nutritional requirements for marine species new to aquaculture
- Studies on emerging feed ingredients with marine species
- Studies on feed ingredients that can be made from co-products of aquaculture products
- Genetics, Nutrition and Physiology are explicitly linked and multidisciplinary research results in improved performance.
- Studies designed to get regulatory approval for ingredients or additives
- Life stage focused studies (larvae, broodstock)

Scientific Discipline - Seafood Science

Vision (s)

- NOAA is the go-to scientific source for aquaculture seafood safety, traceability and identification.

- US aquaculture products are able to be sold and compete worldwide because the world knows US seafood is safe, honest and wholesome.

Key Benefits

- **Environmental**
    - Incentive developed for clean environment
- **Economic**
    - No rejections or losses due to quality, safety or honesty of US aquaculture products
    - Premium paid as reputation improves
- **Social**
    - Confidence in US aquaculture products
    - Less illness

Key infrastructure needs (To be added by scientists)

Research Approach (To be added by scientists)

Scientific Discipline –Stock Enhancement

Vision (s)

- A clear decision support tree to determine when to start a stock enhancement program to benefit fisheries and the environment
- Commercial aquaculture enhances wild stocks by provision of habitat and other ecosystem benefits

Key Benefits

- **Environmental**
    - Increasing fishery yield through hatcheries and responsible stock enhancement to ensure robust populations and sustainable harvests in the face of changes to the natural habitat and variability in stock recruitment.
    - Restoring essential fish habitat (adding vertical structure) and stabilizing shorelines in the face of sea level rise by constructing oyster reefs, planting submerged vegetation, and installing commercial culture gear.
    - Increased resiliency to environmental change
- **Economic**
    - Provision of employment alternatives and maintenance of critical fisheries-related infrastructure such as working waterfront, processing, and distribution capacity.
    - Enhanced recreational fishing opportunities
    - More stable wild capture fisheries
- **Social**

- Enhanced leisure fishing opportunities
- A healthy ocean
- ~~……~~Understanding what level ~~Knowledge that overfishing or habitat degradation can be fixed through~~ stock enhancement and habitat restoration can offer to areas that have habitat degradation and/or a need to supplemental fisheries
- ~~Concerned c~~Citizen scientists ~~s~~ can be actively involved in stock enhancement programs (e.g., making and deployment of oyster bags; submerged vegetation plantings, release of species, adopt a species)

Key infrastructure needs (To be added by scientists)

Research Approach (To be added by scientists)

- Define conditions under which stock enhancement should not be considered as a management tool.
- Conduct strategic assessments by: a) identifying species or stocks that may benefit from aquaculture-based enhancement/restoration, b) modeling potential enhancement of the most important and sensitive species or stocks, and c) assessing the availability or developmental needs for aquaculture technologies to culture the prioritized species or stocks.
- Use quantitative modeling tools incorporating harvest and habitat goals to pre-screen potential enhancement and restoration initiatives to identify those most likely to be effective and to develop realistic implementation plans.
- Conduct real-world tests of genetic, population and ecosystem models applicable to fisheries management and stock enhancement/restoration.
- Use adaptive-management experiments in pilot tests as well as the implementation phase to progressively refine and improve enhancement strategies.
- Develop and test the means to quantify the socio-economic impact of stock enhancement.
- Utilize the Responsible Approach[31] to assess and reform existing marine stock enhancement or species restoration programs.

[31] Blankenship, H.L. and K.M. Leber. 1995. A responsible approach to marine stock enhancement. American Fisheries Society Symposium, 15: 167-175.
Lorenzen, K., K.M. Leber and H.L. Blankenship. 2010. Responsible approach to marine stock enhancement: an update. Review in Fisheries Science, 18(2): 189-210.

Table 4. United States Mandates Regulating the Environmental Impacts of Aquaculture

Issues	Laws
Industry Development	• National Aquaculture Policy Act of 1980 (NOAA/USDA and other agencies) • Sea Grant Act?
Fisheries management, protection of habitat, marine mammals, and endangered species	• Magnuson-Stevens Fishery Conservation and Management Act (NOAA/NMFS) • Marine Mammal Protection Act (NOAA/NMFS) • Endangered Species Act (NOAA/NMFS, FWS) • National Environmental Policy Act (all federal agencies) • Coastal Zone Management Act (NOAA/NOS) • National Marine Sanctuaries Act (NOAA/NOS) • Migratory Bird Treaty Act (FWS)
Nutrient discharges	• Clean Water Act, NPDES discharge permits (EPA) • Safe Drinking Water Act (EPA) • Marine Protection, Research, and Sanctuaries Act (EPA, NOAA/NMFS, USACE)
Siting, hazards to navigation, permitting and construction of structures, transporting product	• Rivers and Harbors Act (USACE) • Clean Water Act, dredge and fill permits (USACE) • Lacey Act (FWS) • 14 U.S.C. 83 (marking structures in navigable waters) (USCG) • Outer Continental Shelf Lands Act (BOEM) • Coastal Zone Management Act (NOAA/States)
Seafood safety, feed ingredients, animal health, use of veterinary drugs	• Federal Insecticide, Fungicide, and Rodenticide Act (EPA) • Federal Food, Drug, and Cosmetic Act (FDA) • Food Safety Modernization Act (FDA) • Hazard Analysis and Critical Control Points Program (FDA) • Surveillance and Monitoring Programs (FDA, ISSC)
Health management, best management practices	• Animal Health Protection Act (USDA/APHIS) • Virus Serum Toxin Act (USDA/APHIS) • 9 CFR 101-124 (regulations on the spread of disease) (USDA/APHIS) • ~~Animal Health Protection Act,~~ • Animal Medicinal Drug Use Clarification Act
Escapes, broodstock management, monitoring and reporting (federal waters)	• Magnuson-Stevens Fishery Conservation and Management Act (NOAA/NMFS)

APHIS = Animal and Plant Health Inspection Service
BOEM = Bureau of Ocean Energy Management
EPA = Environmental Protection Agency
FDA = Food and Drug Administration
FWS = Fish and Wildlife Service
ISSC = Interstate Shellfish Sanitation Conference
NOAA/NMFS = National Marine Fisheries Service
NOAA/NOS = NOAA/National Ocean Service
USACE = U.S. Army Corps of Engineers
USCG = U.S. Coast Guard.
USDA = U.S. Department of Agriculture

Appendix 1 – Inspiration to Innovation

Creating the conditions for Innovation

To be added

How scientific institutions and resources interact for industry advancement

There are multiple structures and institutes that all play a role in creating, funding, directing, transferring and ultimately using science and technology for meaningful aquaculture development (Figure 1). The process of creating new ideas often occurs when a diverse mix of basic and applied research[32] projects interact, typically in the peer-reviewed journals and at scientific conferences. From these diverse studies paradigms[33] are developed through review papers, proceedings and consensus documents. These paradigms often result from special committees or commissions set up just for this purpose. Paradigms are then turned into advice, technology or guidance that is then used by someone. Transferring this information is often facilitated by the end user with tremendous assistance from extension services, use of cooperative agreements, joint institutes, publication and by maintaining transparency. Information resulting from government actions is also subject to the Information quality act (IQA)[34]. NOAA guidelines for advice used for management are outlined in National Standard 2[35] which requires additional external review for advice products used for fishery management. This model for science progress, with some modification, has proven successful in the US and is used by USDA, DOE and other agencies with a technology development and transfer mission. This model is similar to the very successful Norwegian approach which has arguably resulted in the world's most advance aquaculture industry.

Among funders, the federal government is the main source for aquaculture. While state, foundation, and private sector funding is active in the aquaculture world, it differs greatly in motivation, goals, effectiveness and dollar amount. Federal funding is divided between agencies providing grants and those running national labs. Each approach has its own strengths (previously discussed in Section 1) which tend to be complementary when viewed as a whole. No one approach has clear advantage. While agricultural research has evolved from a majority

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[32] Stokes, Donald E. (1997). Pasteur's Quadrant – Basic Science and Technological Innovation. Brookings Institution Press. p. 196. ISBN 9780815781776.

[33] In science and philosophy, a paradigm is a distinct set of concepts or thought patterns, including theories, research methods, postulates, and standards for what constitutes legitimate contributions to a field. See: https://en.wikipedia.org/wiki/Paradigm

[34] The act required the Office of Management and Budget to issue guidance to federal agencies designed to ensure the "quality, objectivity, utility, and integrity" of information disseminated to the public. It also required agencies to issue their own information quality guidelines. See: https://fas.org/sgp/crs/RL32532.pdf

[35] See: https://www.st.nmfs.noaa.gov/science-quality-assurance/national-standards/ns2_revisions

government funded model to a majority privately funded model, this is not yet the case for aquaculture[36]. This is likely due to the much more mature agricultural sector with a strong industry capable of funding much of its own research as oppose to the nascent aquaculture industry, and the large amount of pre-commercialization research already in the pipeline in agriculture. In addition, aquaculture is still developing science-based industry siting and management tools that are only attractive to public funders.

The creators of scientific knowledge are housed in academia, government research labs, business and not-for profit institutes. Hybrids of these institutions can include cooperative institutes or joint research centers, which often can be highly productive because they can take advantage of the strengths of both grant and programmatic funded science. These institutes differ in their mandates, structure and type of funding, and this is reflected in the strengths they bring to the development of aquaculture (Figure 1). Academic institutes typically also have a mandate to educate. Not for profits typically have a specific point of view or approach to the field that may or may not be shared by others or fit with societal goals. Business and industry organizations typically focus on what is best for the bottom line. Government labs focus on the needs of government managers and the mandates they are given by Congress and the Administration, thus reflecting societies interests. The type of funding available (amount and duration) also leads to what various institutions are able to contribute. Long-term stable funding, typical of national labs is needed for long term or infrastructure intensive science. These institutions are also often able to operate at a scale closer to commercial operation, and/or can operate as test-beds for industry. This is also possible for academic institutions with programmatic funding (for example ear marks, endowment, contracts or other long-term stable funding for programs), but is difficult for institutions that rely significantly on short-term project grants. Government labs are also in the best position to develop products that need to comply with the information quality act (e.g. regulatory decision-making tools). On the other hand, shorter-term grant funding is nimble, and facilitates bringing in cutting edge thinking and technology from other fields, a fuller reaction to emerging issues and scalability as budgets vary from year to year. Science advancement in aquaculture will require both types of funding mechanisms and various types of institutes to make meaningful contributions to the sustainable development of the industry.

While individual studies published in the peer-review journals are the bedrock of the process to create scientific knowledge, they are also still just snapshots of information, often vary in quality and are sometimes contradictory in their conclusions. The peer-review literature at this level serves as a first course filter of information quality, and the primary literature serves as a venue for an intellectual conversation about a topic among researchers. It is not until a group of studies on a topic is synthesized into a paradigm that it becomes useful outside of the discipline. The first synthesis step also affords another opportunity for peer-review which ideally improves the information quality from the primary literature. A paradigm typically provides a general model of the subject. Additional synthesis is then needed for the

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[36] See: https://www.usda.gov/media/press-releases/2012/11/26/usda-study-shows-trends-public-and-private-agricultural-rd

development of specific advice, technology or guidelines to be operationalized. Advice products used by the government typically afford a third peer-review[3], further improving the information quality. The quality of technology is often further enhanced through the use of test beds, work conducted at a scale appropriate for the technology's final use (e.g. pilot scale), and/or located under the conditions of its final use (e.g. on-farm studies). While it is not always the case, the paths of advice for government typically involves government employees from labs and the end user agency working together. Technology often relies on extension dealing with technology transfer to industry, and use of cooperative studies either at labs or on farms.

A final key ingredient to optimizing the creation of scientific advances for aquaculture deals with management of the process (See arrows in figure 1). Effective management requires excellence in two areas; 1) communication and 2) strategic planning. Tools to enhance communication include extension services, the ability to conduct cooperative multi-disciplinary research (to include researcher and end users), transparency, periodic program reviews and benchmarking. Tools to develop strategic planning include interagency coordination, processes for stakeholder engagement, periodic program reviews, and open formal processes for strategic planning.

Table 2. Attributes of innovation producing organizations (idea parking lot).

Attribute	Explanation quoted from Reference	References
A talented and interconnected workforce	"The importance of talent cannot be overstated. Talent benefits not only from traditional education and research training in science and engineering, but also from immigration; partnerships; supportive research environments; and the worldwide networks through which researchers connect with others, develop professional relationships, and share ideas and scientific resources. International collaborations are an increasingly important mechanism allowing the United States to rapidly apply knowledge gained through research investments in other areas of the world."	National Research Council. (2014). Furthering America's Research Enterprise. R.F. Celeste, A. Griswold, and M.L. Straf (Eds.). Committee on Assessing the Value of Research in Advancing National Goals, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
Adequate and dependable resources	"Stable and predictable federal funding encourages talented students to pursue scientific careers, keeps established researchers engaged over a career, and attracts and retains foreign talent. It also supports a diversity of institutions, that both fund and conduct research, as well as essential scientific infrastructure—the tools necessary for conducting research. Stable resources are increasingly important to future competitiveness given the rising investments in research by other	National Research Council. (2014). Furthering America's Research Enterprise. R.F. Celeste, A. Griswold, and M.L. Straf (Eds.). Committee on Assessing the Value of Research in Advancing National Goals, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

	countries, particularly China and other Asian nations." "Of particular concern is the future funding of high-risk, long-term research and of proof-of concept research, which helps bridge the gap between research and development through the development of innovations." "…many research discoveries intended for future development and commercialization, such as the technology used to develop efficient fuels, must first cross the so called"valley of death"—the often prohibitive cost and risk associated with proof-of-concept research. In some cases, the industry and venture capital support needed to develop a concept or invention vastly exceeds the funding for the original concept or invention.	
World-class basic research in all major areas of science (or at least a connection to it)	Basic research, in which investigators pursue their ideas primarily for increased understanding and not necessarily toward a technological goal, often provides the foundation of discovery and knowledge for future economically significant innovations. "…a broad and deep knowledge base is necessary for the development of new technologies."	National Research Council. (2014). Furthering America's Research Enterprise. R.F. Celeste, A. Griswold, and M.L. Straf (Eds.). Committee on Assessing the Value of Research in Advancing National Goals, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
Truly transformative scientific discoveries often depend on research in a variety of fields	Maintaining broad expertise among those who conduct research also sustains the innovation system, because technological problems often arise in the development of an innovation that require research for their solutions. Research and innovation are symbiotic in this way. Similarly, many aspects of manufacturing contribute to and draw on research.	National Research Council. (2014). Furthering America's Research Enterprise. R.F. Celeste, A. Griswold, and M.L. Straf (Eds.). Committee on Assessing the Value of Research in Advancing National Goals, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
Critical Mass – two small programs lack enough diversity to allow for growth and interconnectedness, two large makes meaningful communications difficult		Johnson Gladwell
Connection to end users		Stokes Farming systems/extension literature
Adjacent Possible Theory		Kaffman Johnson https://www.youtube.com/watch?v=R9Mn1bppV7U
Focus		
Open access inventions		Johnson

Balance between competition and collaboration		Johnson
Other/Placeholder	This review paper summarizes some of the critical factors that influence aquaculture technology adoption decisions such as: (1) method of information transfer, (2)characteristics of the technology, (3) farm characteristics, (4) economic factors, and (5) sociodemographic and institutional factors.	Kumar et al

Figure 1. A model of the creation, funding, direction and use of scientific information for aquaculture in the US. Green, blue and purple signify primary roles for extramural grant programs, national labs and non-science stakeholders (government, NGO and/or industry), respectively.

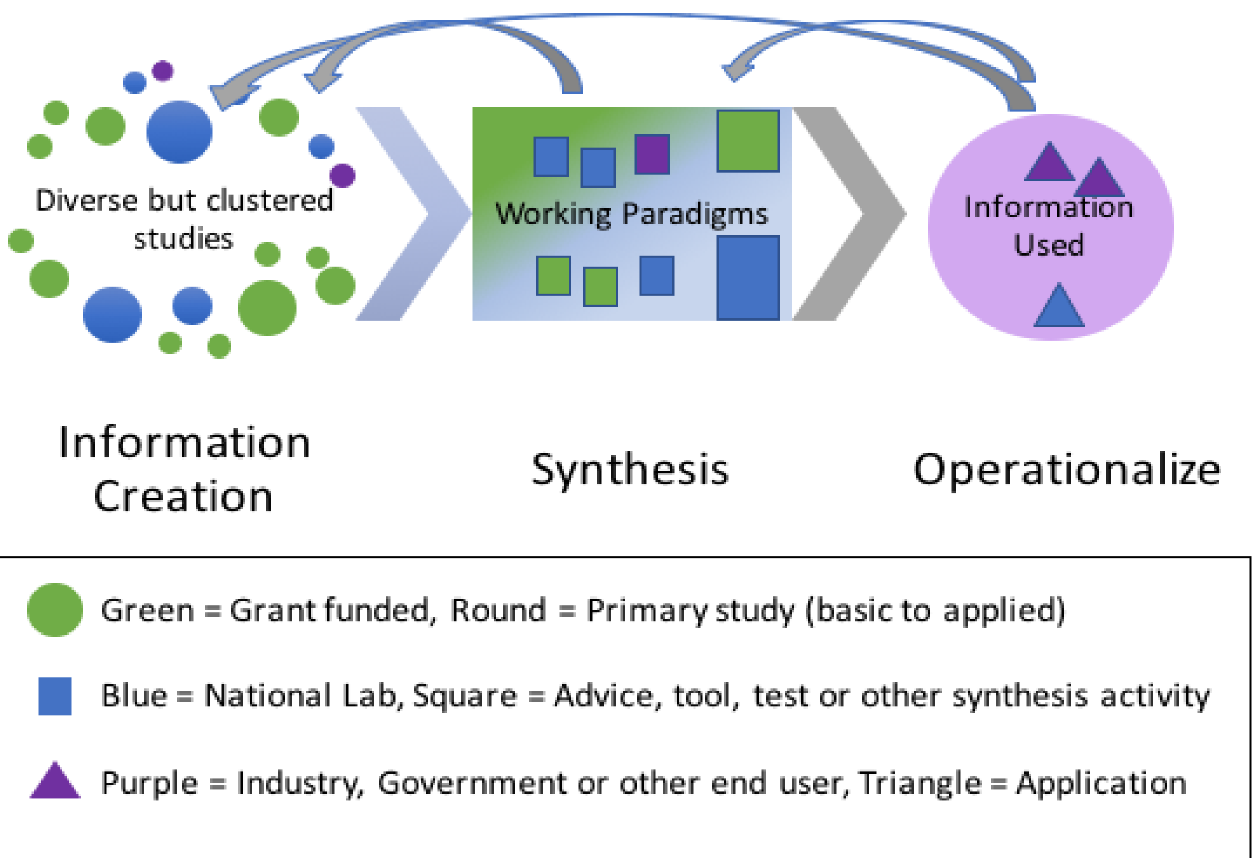


Figure 2. Conceptual development of science-based tools to aid in regulatory streamlining. Green, blue and purple signify primary roles for extramural grant programs, national labs and non-science stakeholders (government, NGO and/or industry), respectively.

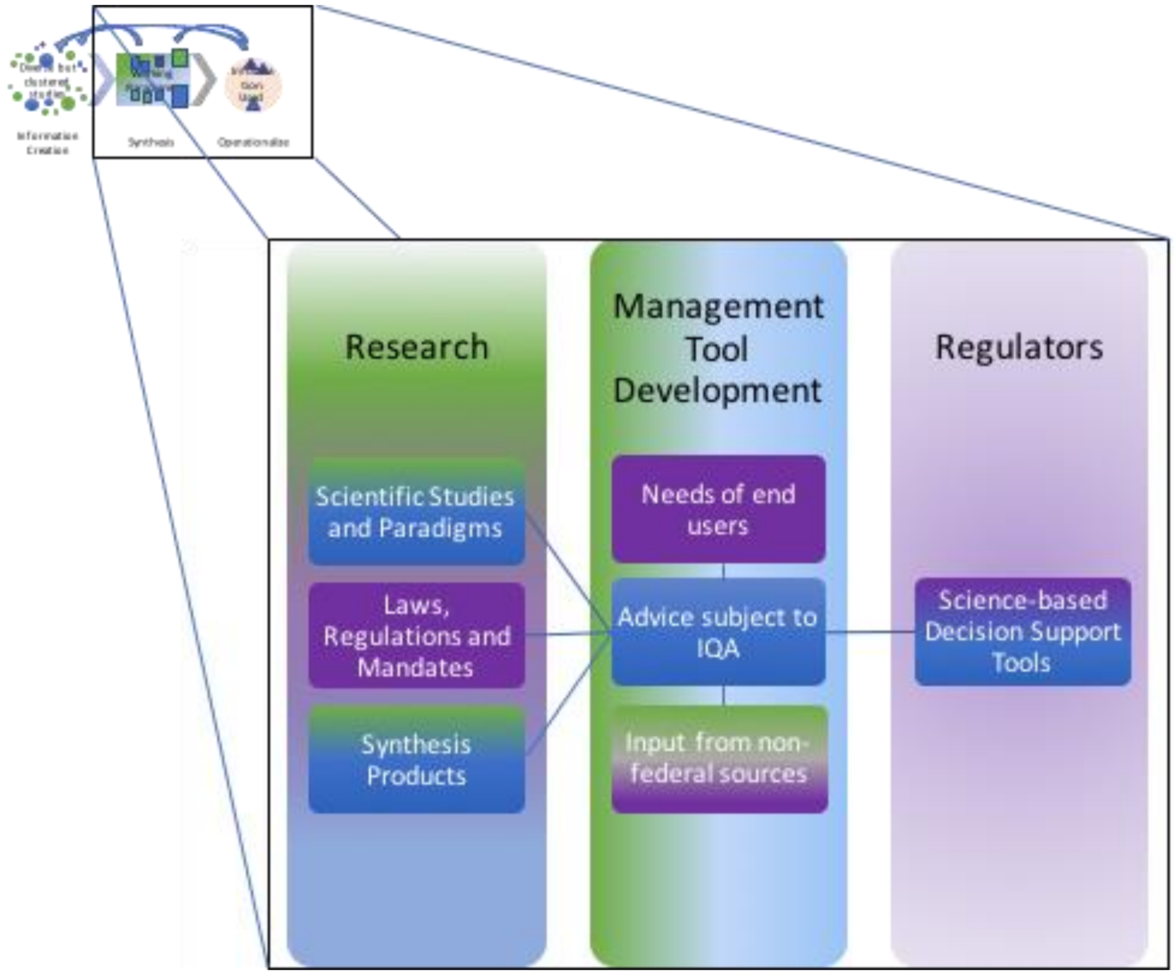
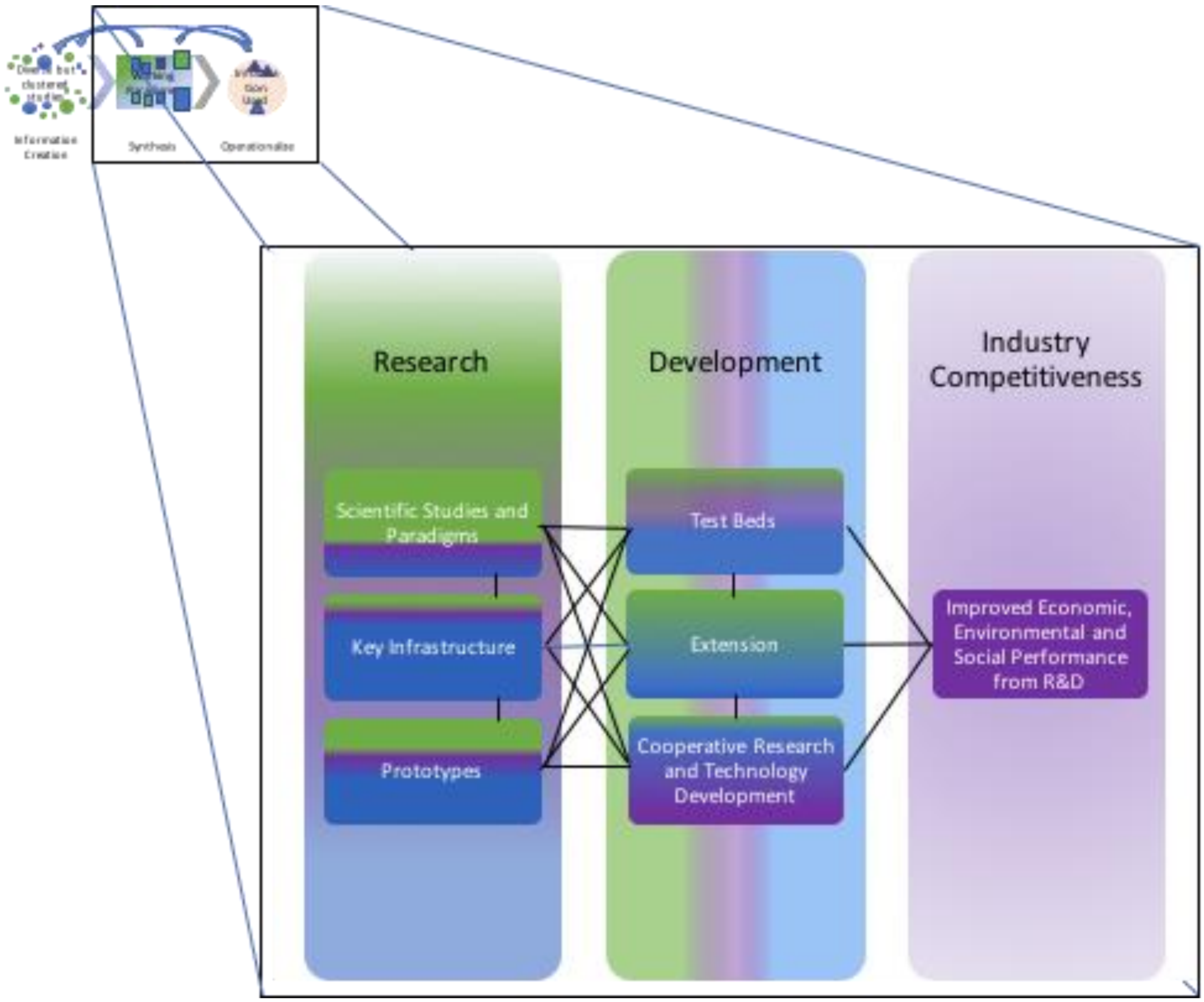


Figure 3. Conceptual development of science and technology to enhance industry competitiveness and viability. Green, blue and purple signify primary roles for extramural grant programs, national labs and non-science stakeholders (government, NGO and/or industry), respectively.



Appendix 2 – Proposed R2X guide

NOAA Aquaculture Program Principal Investigator Guide:
Self-Reporting on Research to Application Performance Measure

Purpose:
This document provides guidance to aquaculture project Principal Investigators (PI) on how to self-report on the three categories of Research to Application (R2A) performance measures.

Background:
NOAA administration requested development of a performance measure to track the NOAA Aquaculture Program's (AQP – includes all NOAA lines) research and development (R&D) efforts. It is of particular importance to have an appropriate measure to report on the Department of Commerce's Strategic Plan (2018 – 2022) where the aquaculture performance indicator, "Percentage of target research advances accomplished" was included. With the recognition that advancements in science are difficult, often intangible, and multi-dimensional commodities that are invariably attributable to a great number of predecessors[37], measurement is an integral necessary part of management of all sorts of enterprises including science and is now required by Administrative Order.[38]

The Office of Oceanic and Atmospheric Research (OAR) previously developed a Research to Application (R2A) performance measure to track R&D efforts. AQP is using OAR's R2A performance measure as a basis for the AQP research performance measure with adjustments making it appropriate for the specific needs of the AQP and to help consistent estimation of R2A across NOAA (Grants, Labs, and Partnerships). Tracking AQC's R2A performance measure will require that PI's self-report on the transitions that are accomplished as a part of the existing reporting structure. These will then be added to the NRDD by the funding line office.

In order to accommodate the different types of applications for AQP's research efforts, there are three categories of R2A performance measures:

1- Research to Operation (R2O): Unique, self-contained unit of change (e.g., configuration change tracked element, an entire new technology system)
2- Research to Commercial (R2C): Patents commercialized, licenses sold, etc.
3- Research to Other Uses (R2U): Policy, Regulations, Resource Management, Public Education and Outreach, etc.

PI's research projects should fall in to one of these three categories of R2A performance measures. Each will have a slightly different structure for quantifying progress to application. The following sections will provide explanations of the three different quantifying structures. In

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[37] NRC 2017 (add text)

[38] Administrative Order (NAO) 216-115: Strengthening NOAA's Research and Development Enterprise

addition, specific AQC projects that represent each of the three categories of R2A will be included to provide further clarification.

Research to Operation (R2O):
You will determine which of the following R2O Readiness Levels (RL) your research project falls in for the current reporting period.

Readiness levels and stages

RL l: Basic research, experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Basic research can be oriented or directed towards some broad fields of general interest, with the explicit goal of a range of future applications[39].

RL 2: Applied research, original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. Applied research is undertaken either to determine possible uses for the findings of basic research or to determine new methods or ways of achieving specific and predetermined objectives[3].

RL 3: Proof-of-concept for system, process, product, service or tool; this can be considered an early phase of experimental development; feasibility studies may be included.

RL 4: Successful evaluation of system, subsystem, process, product, service or tool in laboratory or other experimental environment; this can be considered an intermediate phase of development.

RL 5: Successful evaluation of system, subsystem process, product, service or tool in relevant environment through testing and prototyping; this can be considered the final stage of development before demonstration begins.

RL 6: Demonstration of prototype system, subsystem, process, product, service or tool in relevant or test environment (potential demonstrated).

RL 7: Prototype system, process, product, service or tool demonstrated in an operational or other relevant environment (functionality demonstrated in near-real world environment; subsystem components fully integrated into system).

RL 8: Finalized system, process, project, service or tool tested, and shown to operate or function as expected within user's environment; user training and documentation completed; operator or user approval given following process to ensure compliance with the Information Quality Act (typically an external review).

RL 9: System, process, product, service or tool deployed and used routinely.

[39](OECD, 2015); NOAA research projects are not typically in TR 1. See: (Spinrad doc)

NOAA Technical Readiness Levels (RLs)		Stage[40]
1	Basic principles observed and reported	Research
2	Technology concept and/or application formulated	
3	Analytical and experimental critical function and/or characteristic proof-of-concept	Development
4	Component/subsystem validation in laboratory environment	
5	System/subsystem/component validation in relevant environment	
6	System/subsystem model or prototyping demonstration in a relevant end-to-end environment	Demonstration
7	System prototyping demonstration in an operational environment	
8	Actual system completed and "mission qualified" through test and demonstration in an operational environment. Passed Information Quality Act review as needed	
9	Actual system "mission proven" through successful mission operations	Operations

Example aquaculture research projects where the R2O performance could be applied:

a. Offshore Mariculture Escapes Genetics Assessment (OMEGA) model: was developed by NMFS researchers and is used to identify and evaluate the genetic risks associated with marine aquaculture operations, recommend management practices for responsible and sustainable aquaculture programs, explore the effects of regulatory and technical advances, and identify research priorities.

[40] NOAA funding line offices will consolidate nine Technical Readiness Levels (TRLs) into just four maturity stages (research, development, demonstration, and applications/operations):
"Research" stage to "Development" stage, with the threshold between TRL2 and TRL3. "Development" stage to "Demonstration" stage, with the threshold between TRL5 and TRL6. "Demonstration" stage to "Operations"; with the threshold between TRL8 and TRL9. Employment in operations is necessary to achieve this threshold.

b. Gulf Aquamapper: is a web-based tool developed by National Ocean Service (NOS) researchers for exploration, permitting and siting of offshore aquaculture in the Gulf of Mexico. The Gulf AquaMapper is a geodatabase featuring aquaculture-relevant GIS data for biological, navigational, military, social, economic, physical and chemical parameters. The Gulf AquaMapper can be used as a one-stop screening solution for industry and coastal managers focused on identifying suitable areas for aquaculture development. In particular, the tool aims to streamline the permitting process established by the Gulf of Mexico Fishery Management Council in 2016, by reducing logistical and economic inefficiencies for coastal managers and aquaculture investors. The Gulf Aquamapper could also be tracked with an R2C performance measure because it is intended for use by industry, however since it is ultimately to improve permitting, an R2O performance measure is more appropriate.

<u>Research to Commercial (R2C)</u>:

R2C is reported in a similar way as R2O except the final stages (RL8 and RL 9) transition the innovation to the private sector. You will determine which of the following R2C Readiness Levels your research project falls in for the current reporting period.

Readiness levels and stages
RL 1-7 are the same as R2U;
RL 8: Finalized system, process, project, service or tool tested, and shown to operate or function as expected within user's environment; user training and documentation completed; operator or user approval given;
RL 9: System, process, product, service or tool deployed and used routinely.

The transition of NOAA research into the commercial sector is currently measured by NOAA's Technology Partnerships Office (TPO) in terms of patents, intellectual property licenses, and Cooperative Research and Development Agreements (CRADAs). Patents, by themselves, do not represent a transition of research to usage (application); however, the commercialization of a patent does; consequently, an appropriate performance measure with respect to patents would address their commercialization rate. Intellectual property licenses represent commercialized use and, therefore, the transition from research to application. CRADAs address the terms of collaboration, rather than the transition of results; consequently, CRADAs are a separate measure from the transitions performance measure framework outlined in this document.

Example aquaculture research project where the R2O performance could be applied:

a. Strain OY15 Probiotic: NMFS researchers identified a Vibrio sp. bacterium (OY15), isolated from oysters, that significantly improves survival of larval oysters (*Crassostrea virginica*) challenged with a Vibrio sp. shellfish-larval pathogen. Molluscan shellfish hatcheries across the U.S. will benefit from eventual availability of probiotic bacteria as a component of "functional feeds," to increase seed production. NMFS is currently partnering with a private company to transition this product to a commercial product. A

Material Transfer Agreement was completed and a Cooperative Research and Development Agreement (CRADA) is planned to run commercial-scale trials.

Research to Other Uses (R2U):

A broad spectrum of applications utilizing R&D results exists beyond operations and commercialization, such as to policy, regulations, resource management, public education and outreach, etc. Such applications of R&D constitute transitions and are recorded with the same metrics as R2O/R2U as appropriate.

Example aquaculture research project where the R2O performance could be applied:

FDA approval of taurine: Taurine is a nutrient that carnivores need in their diet and is a key nutrient needed to make plant proteins nutritionally similar to other animal proteins. A joint NOAA and USDA feeds initiative identified taurine as a key need in fish feeds in 2011. NMFS researchers demonstrated that taurine is an essential nutrient for some cold water marine fish and developed guidelines. Based on this research and numerous other studies, a group of nutritionists and industry representatives petitioned the FDA to allow taurine as an ingredient in fish feed. FDA approved use of taurine in 2017. This is an example where NOAA research resulted in policy change.

Additional Information:

The following information should be used, ***as appropriate***, to inform consideration of the maturity of activities, with the understanding that not all projects fit cleanly into these definitions so use of some judgment may be required.

NOAA Definitions

NSF Definitions

a. **Research**: Systematic study directed toward a more complete scientific knowledge or understanding of the subject studied. Research is classified as either basic or applied according to the objectives of the sponsoring agency:

i. **Basic Research**: In basic research, the objective of the sponsoring agency is to gain fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind.

ii. **Applied Research**: In applied research, the objective of the sponsoring agency is to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.

b. **Development**: systematic use of the knowledge or understanding gained from research, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes. It excludes quality control, routine product testing, and production.

c. **Demonstration**: activities that are part of research or development (i.e., that are intended to prove or to test whether a technology or method does, in fact, work) should be included. Demonstrations intended primarily to make information available about new technologies or methods should not be included.

NASA Definitions of Technology Readiness Levels (TRLs)

TRL 1 Basic principles observed and reported: Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

TRL 2 Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept: Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.

TRL 4 Component/subsystem validation in laboratory environment: Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.

TRL 5 System/subsystem/component validation in relevant environment: Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.

TRL 6 System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space): Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.

TRL 7 System prototyping demonstration in an operational environment (ground or space): System prototyping demonstration in operational environment. System is at or near scale of the operational system, with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.

TRL 8 Actual system completed and "mission qualified" through test and demonstration in an operational environment (ground or space): End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.

TRL 9 Actual system "mission proven" through successful mission operations (ground or space): Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

Developing world class marine aquaculture science at NOAA

Terms of Reference

Deliverable:

- Develop a NOAA vision and strategic plan for research and development that addressees:
    - Needs for aquaculture science in the US by geography, expertise and infrastructure
    - At the level of the Current budget vs. $40M increase.
    - Considers full R2X of science flow
    - Using internal labs, partnerships, extension and grant programs and SG universities
    - Consider roles of ICES and other international bilateral agreements
    - Recommends and identifies facilities needed for world-class science, extension, industry development and workforce (including public managers) training, and potential to leverage through partnerships or other administrative structures
    - How to deliver science, science-based tools and technology to managers and industry to benefit society?

Rationale:

- Given options for future seafood procurement, increasing aquaculture is a must.
- Aquaculture under US law must also consider, and ideally provide ecosystem services (Developing in an ecosystem approach or context)
- NOAA has a good aquaculture science foundation but it is not enough - we need better coverage geographically, by discipline and by organism type as pointed out in the Review
- NOAA's internal labs, extramural grants and extension services lack a common well-articulated vision and strategic plan to achieve it.
- Opportunity to leverage with other agencies (USDA, DOE, etc), industry, NGO's and internationally (Bilateral, ICES, PICES etc) could be explored.

Existing Plans and Reviews

- NOAA Aquaculture Plan
- NOAA Science Center Review
- Federal Strategic Plan
- Sea Grant Plan
- NOAA Strategic Plan
- Ocean Policy (under revision)
- DOC Strategic Plan

Agency Management Science Needs

- Tools for regulation and planning
    - NOAA Mandates:
        - Protected Resources
        - Habitat

            - Managed Fisheries
    - Other Agency Mandates NOAA could provide leadership on
        - NEPA
        - ACOE
        - Other
    - Forward looking tools for communication

Industry Needs

- Triple bottom line technologies to
    - improve economic,
    - environmental and
    - social performance
- Topics need review and prioritization for NOAA

Other Considerations:

- Congress has signaled that partnerships (especially public-private) are important and need to be a part of the plan
- Regional vs Targeted vs hybrid?
- Budget is unknown but small relative to needs. Consider two levels
    - Current – status quo about $20M/yr
    - Increase to $60M/yr total spent (based on AQUAA act numbers)